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Quest for fatigue limit prediction under multiaxial loading

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Abstract

The paper discusses origins of fatigue data used for evaluating the prediction quality of various multiaxial methods intended for estimating the fatigue limit. The paper defines some requirements useful for processing similar data sets. It focuses on four most often used data sets, analyzes the way they were prepared and the way they are transmitted over various research papers. These sets are commented and objections to some their items stated. Weight coefficients enabling their application in validation studies are proposed. The final reduced total set has approximately one half of its original size. The reduced set is re-analyzed by several fatigue limit calculation methods and the results are compared to the origin. Though the relative probability distribution of the output is quite well kept, the importance of evaluating the second hand data sets carefully is clearly highlighted.

Keywords: multiaxial fatigue; fatigue limit; multiaxial fatigue limit estimation; experimental fatigue data; fatigue database

1. Introduction

Evaluating various models for estimating the fatigue limit under multiaxial loading has its tradition. The data sets on load conditions under multiaxial loading leading to the fatigue limit were reused paper by paper, with the obvious winning test set recorded by Nishihara and Kawamoto in 1945 [1]. Initially, this kind of evaluating the criteria was largely affected by a patient work of German PhD students and scientists starting from the seventies of the 20th century [2-6]. Except for their experimenting activity, they often proposed own methods for multiaxial fatigue limit estimation, and were therefore looking for more data sets to validate their proposals. Looking back to older data sets by Gough [7-9], Findley [10], Nishihara & Kawamoto [1], they started to build a kind of a database, which was topped by the work of Troost, Akin and Klubberg in 1992 [11]. No set of similarly broad range seems to be

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published in a single journal paper, though this one was realized in German. Weber [12] used a lot of similar data sources and maybe was inspired by it. Weber anyway did not proceed to publish his testing in a research paper, and stayed with his French PhD thesis [12]. The last recorded similar action was started by Papuga in [13], who did not published the individual items of the test, but only an overview with a link to a data repository on [45].

A lot of minor sets were published meantime, starting above all with McDiarmid [14], Papadopoulos [15-16], and continuing by others [17-32]. The data sets there are substantially smaller, and often cited from one paper to another. Due to the lower number of data items, the statistical significance of the output is also low [13].

It is unknown, how careful effort the individual authors spent on validating the input test data they used. This paper is a partial result of a long-term search for original papers. It analyzes, whether the current knowledge on applicability of various criteria in this category is based on an observed reality, or if the way of managing the input test data could invalidate it.

Nomenclature

ΔFI	fatigue index error [%] – see Eq. (2)
f_{-1}	fatigue limit in fully reversed axial loading [MPa]
f_0	fatigue limit in repeated axial loading [MPa]
N	number of cycles till break [-]
R^2	coefficient of determination [-]
σ	stress [MPa]
t_{-1}	fatigue limit in fully reversed torsion [MPa]

2. Evaluating quality of the fatigue limit estimate

2.1. Method of evaluating

The criteria evaluating local stresses towards the fatigue limit are usually formulated as the inequality:

$$L.H.S.(\text{local stresses}) \leq R.H.S.(\text{material parameter}) \tag{1}$$

Anyhow, if the method for determining the left-hand side *L.H.S.* is scrutinized, it is usually done by testing the method on experimental data related to the fatigue limit of a given material, which forms the material parameter on the right-hand side *R.H.S.* The two sides of the inequality have be equal then, but it happens only rarely. Fatigue index error ΔFI is defined as a relative deviation between the left- and right-hand sides:

$$\Delta FI = \frac{L.H.S. - R.H.S.}{R.H.S.} \cdot 100\% \tag{2}$$

A similar kind of evaluation can be traced back to Papadopoulos [15] and maybe beyond. Later it became a dominant solution for evaluating the closeness of the prediction method to the fatigue behavior manifested by the experiments. Papadopoulos' predecessor McDiarmid [14] used just evaluation of the ratio *L.H.S./R.H.S.* Papadopoulos [15] inspired others also by providing an overview of the results in histograms similar to Fig. 2 here. The distribution of the number of occurrences of the fatigue index error in the test set is described there. He defined the margin ±5% of the fatigue index error to designate the optimum prediction, while ±10% of ΔFI was declared as sufficient. The histograms provided by Papadopoulos [15] and his followers [17-32] nevertheless clearly exhibit, that keeping the content within ±15% is close to a miracle. Papuga in [13] realized a large-scale evaluation on the data set of 407 experiments and ended up with most of the methods falling outside of the ±40%, with the only exception for the Papuga PCr method within the approximate range ±20%.

If such classification is accepted, emphasis should be put on precision of quantities used for feeding Eq. (2). If evaluating and sorting of the calculation methods is grouped to smaller sets as Papuga did in [13], the established groups of experiments have also to contain enough items to provide an applicable conclusion.

2.2. Preparing input data

There are two methods for preparing the fatigue limits used in such kind of evaluations. The optimum solution is using the staircase method [38], which evaluates the occurrence of failures at a given number of cycles on various stress levels. This kind of fatigue testing ends in one point of the whole S-N curve. Due to spending the whole experimental effort on high numbers of cycles, the experimenting is linked with high costs. Other solution is therefore more often used. The data points of the S-N curve in its high-cycle fatigue region are generated by tests, and a particular number of cycles are defined to correspond to the fatigue limit.

Such a solution brings along some difference in comparison to the staircase method, because of these reasons:

1. The result can be based on positions of data points far away from the target area close to the fatigue limit.
2. The kind of the S-N curve approximation affects the output.
3. In case that the most widely used Basquin regression formula is applied, including or excluding data points in the outer parts (e.g. close to the fatigue limit or in the quasi-static area) is subjective.
4. S-N curves of one material from one lot needn't to have the bend at the same number of cycles, e.g. for high constant pre-loads the bend can be often found elsewhere.
5. The minimum potential of deviation of the regressed fatigue curve from the real one is in its central part, while the fatigue limit region is covered with the least certitude.

Obviously, many items contradict using this type of the data input, but some mitigation of conditions is necessary. FADOFF consortium working on this topic thus sets the following rules for processing such inputs:

- No extrapolating outside the region bordered by the outermost completed experiments.
- Optimum minimum number of data points per the S-N curve is 8, if the scatter is not too high. Any decrease of the number of specimens must be evaluated carefully and the weight of such fatigue limit estimates should be decreased (see the used proposal in first four columns in Table 1). Though attempts to set the weight on a basis of a rigorous analysis are underway in the FADOFF consortium, the weights in Table 1 are set as a linear dependency between an expected minimum of specimens in an optimum set (8) and an expected minimum of specimens in a still acceptable set (4).
- In order to assess the multiaxial methods, the data on the fatigue limit estimates for two basic load modes – single alternate push-pull and single alternate torsion – should be provided conforming to the two conditions above. For more sophisticated evaluation methods, the repeated tension mode can be necessary. Methods based on its use cannot be evaluated without this information.
- The data items with complete sources (e.g. individual data points of S-N curves in a table) are required. The input data can be retrieved from graphs as well, but these are accepted with a weight coefficient decrease to one half (see Table 1). This reduction is very rough, because the quality of graphic input can differ (most of the graphs in the middle of the 20th century were drawn by hand), some reduction is anyway necessary.
- Two S-N curve approximations are evaluated, and the one with better coefficient of determination R^2 is used for generating the fatigue limit value.

Table 1. Rules for setting the weight coefficients to individual fatigue limit items deduced either from the whole S-N curve or from the staircase method.

S-N curve			
Number of specimens	Weight	Number of specimens	Weight
8	1	5	0.4
7	0.8	4	0.2
6	0.6	< 4	0

S-N curve & Fatigue limit	
Data source	Weight
table	1
graph	0.5

Fatigue limit	
Set size	Weight
optimum set	1
reduced set	0.5

In addition to the well known Basquin-type formula:

$$\sigma^{w} \cdot N = const\,, \tag{3}$$

another solution proposed by Kohout and Věchet in [39] is used:

$$\sigma = a \cdot \left(C \cdot \frac{N+B}{N+C} \right)^{\beta}. \tag{4}$$

The parameters a, B, C, β, w and *const* are related to the material, kind of loading, type of the specimen, etc., while σ stands here for stress and N for the number of cycles. The approximation in Eq. (4) was selected based on reasoning of authors [39], very good results for evaluated experimental data and smooth transitions to the fatigue limit area and to the quasi-static range, which avoids any subjective evaluation necessary while using Eq. (3).

3. Evaluated data sets

Table 2. Matrix of test sets evaluated in selected papers. FatLim code row corresponds to the marks used in the FatLim database on [45].

FatLim code		NKh	NKm	NKc	NKd	HRZ	FLA	FLB	Lem	Mie	SP	Rot	GPx	Ggh	Fin	Iss
	Material	hard steel	mild steel	cast iron	duralumin	34Cr4	30NCD16	30NCD16	42CrMo4V	25CrMo4	6082 T6	0.35%C steel	various steels	S65A	76S-T6	Issler
Paper by Year	Ref	[1]	[1]	[1]	[1]	[33]	[34]	[35]	[5]	[6]	[36]	[37]	[7, 8]	[9]	[10]	[3]
McDiarmid 1987	[14]	x	x	x	x											
Papadopoulos 1994	[15]	x				x		x								
Papadopoulos et al. 1997	[16]	x				x		x	x							
Carpinteri, Spagnoli 2001	[17]	x	x	x												
Mamiya, Araújo 2002	[18]	x				x		x	x	x						
Banvillet et al. 2003	[19]						x	x								
Cruz, Zouain 2003	[20]	x	x			x			x							
Goncalves et al. 2004	[21]	x				x		x								
Goncalves et al. 2005	[22]	x				x		x	x							
Liu, Mahadevan 2005	[23]	x	x	x		x		x	x							
Ninic 2006	[24]	x	x	x	x						x					
Ninic, Stark 2007	[25]	x	x	x	x			x			x	x	x		x	
Braccesi etal 2008	[26]	x				x		x	x							
Papuga, Ruzicka 2009	[27]	x	x			x	x	x	x					x		
Shariyat 2009	[28]	x				x		x	x							
Li, Reis, Freitas 2009	[29]	x				x		x		x						
Vu et al. 2010	[30]	x	x			x	x	x	x	x				x		
Carpinteri et al. 2011	[31]	x	x	x	x		x	x				x			x	
Matsubara, Nishio 2013	[32]	x				x		x	x	x						x
Number of occurrences		18	9	6	4	13	4	15	10	4	2	2	1	2	2	1

The overview of typical data sets used in similar analyses is provided in Table 2. The list is far from being complete, but still manifests some trends. As the years go on along vertical axis, the number of used data sets increases and the composition of the test sets gets more diversified. Several sets are obviously dominant. Except for one paper by Banvillet et al. [19], all other papers use the set on hard steel recorded by Nishihara and Kawamoto [1]. Though they provided results to 3 other materials, this material is the most often used. Anyhow, if the influence of a single paper on experimental data sets is evaluated, the total number of occurrences of all four tests from [1] stops by 37, i.e. nearly twice per one paper in the list. The next very important test sets are those by Heidenreich et al. (HRZ, [18]), Froustey (FLB, [20]) and Lempp (Lem, [5]). These sets can be traced back to Papadopoulos et al. [16].

3.1. Nishihara and Kawamoto

As noted in Table 2, these two Japanese scientists provided data on experiments realized on four different materials, with various combinations of plane bending and torsion. The experiments included various phase shifts between the load channels, which makes them interesting for multiaxial analyses. Thanks to no mean stress effect involved, most of the computational methods attain quite good results.

Note, that Carpinteri and Spagnoli in [17] cite the individual values erroneously. Maybe the strangest in their reference is the use of different values for fatigue limits in fully reversed push-pull and fully reversed torsion, when cited as material parameters, and when cited among all other experimental results. The values of experimentally set fatigue limits do not correspond to Nishihara's and Kawamoto's results, and a typical increase of referred stresses by 2-9% can be found, while the material parameters are cited correctly. Any re-use of Nishihara and Kawamoto test set from [17] should be prevented.

Table 3. Overview of experimental data provided by Nishihara and Kawamoto in [1]. Coefficient of determination of the S-N curve formula approximation by Eq. (3) is set only for curves defined by at least 3 data points of completed experiments. The datapoints are described in *a*+*b* coding - *a* stands for completed experiments, *b* is the number of interrupted experiments.

hard steel	data points	R^2	mild steel	data points	R^2	cast iron	data points	R^2	duralumin	data points	R^2
NKh01	4+1	0.983	NKm01	1+1	x	NKc01	1+1	x	NKd01	1+0	x
NKh02	2+1	x	NKm02	2+1	x	NKc02	1+1	x	NKd02	1+0	x
NKh03	2+1	x	NKm03	2+1	x	NKc03	2+2	x	NKd03	3+0	0.958
NKh04	3+1	0.916	NKm04	1+1	x	NKc04	1+2	x	NKd04	2+0	x
NKh05	3+1	0.984	NKm05	2+1	x	NKc05	1+1	x	NKd05	2+0	x
NKh06	2+1	x	NKm06	3+1	0.300	NKc06	1+2	x	NKd06	2+0	x
NKh07	2+1	x	NKm07	2+1	x	NKc07	1+1	x			
NKh08	3+1	0.967	NKm08	2+1	x	NKc08	3+1	-4.126			
NKh09	4+1	0.916									
NKh10	4+1	0.869									
NKh f_{-1}	4+1	0.743	NKm f_{-1}	4+3	0.916	NKc f_{-1}	4+3	-1.481	NKd f_{-1}	4+1	0.891
NKh t_{-1}	5+1	0.724	NKm t_{-1}	3+1	0.985	NKc t_{-1}	2+2	x	NKd t_{-1}	4+1	0.975

The paper [1] provides tables with every single experimental result described, which is the optimum solution to transmit the research data. Nevertheless, when the individual setups are summarized in Table 3, it becomes obvious that the applicability of such data to determining the quality of fatigue limit estimation methods is improper. Only one fatigue curve could be approximated based on 5 completed experiments. If the base data under uniaxial load modes serving as the feed for material properties of the model in Eq. (1) are evaluated, only hard steel and duralumin could be accepted if deriving the fatigue limit from the S-N curve defined by 4 completed experiments only. This is far below the original optimum requirement stated in Sec. 2.2. There is not a single multiaxial curve for duralumin, which could be used. The coefficient of determination for the uniaxial experiments on hard steel is quite low. If accepted like that, only three multiaxial items can be used, if 4 completed experiments are claimed to be enough. The proposed weight of these data items in evaluating the computational methods is set to 0.2 (see Table 1).

3.2. Heidenreich et al.

The set referred in Table 2 is marked as HRZ. It is just a part of the experimental results provided by Heidenreich et al. during the eighties of the 20th century [33]. The staircase method was used for determining the fatigue limits at 1.500.000 cycles, mostly by 12-13 specimens. A part of the experiments is referred to as “Stichversuche” i.e. sampling tests. In such a case, the fatigue limit was set based on 5-6 specimens.

The common setup of the HRZ set relates to 14 experiments cited by Papadopoulos in [16]. From this data set, HRZ04 and HRZ06 referred in FatLim notation correspond to sampling tests. FatLim refers to additional HRZ15-18 experiments. After the careful search, HRZ15-17 data proposed by Weber in [12] are ready for discarding. No evidence on their existence is found in papers by Heidenreich et al. while the number of experiments used for deriving HRZ18 has not been found at all.

The other sets defined by this team on 34Cr4 in FatLim are marked Hei and HZ. They are prepared on other two lots of material. The test setups are similar to the HRZ set. The use of the HZ test set should be wholly abandoned, because the pure alternate torsion curve has not been determined at all.

Checking the most often cited test data HRZ01-14, the weight factor is set to 1, except for HRZ04 and HRZ06, which are described by less than one half of specimens. The weight of these data items is set to 0.5.

3.3. Froustey

FLB test set can be traced back to the PhD thesis of Froustey [35], while FLA was published later in [34]. Froustey describes to get three lots of 30NCD16 from Société Aerospatiale. The first set was used for rotating bending and torsion and the other two sets were realized in plane bending and torsion. The most often cited FLB set is linked to the second lot, for which the uniaxial fatigue curves in push-pull and torsion were set. Mostly 12 specimens were tested within staircase scheme of evaluation. To save some specimens and lower the costs, Froustey diminished the number of specimens for FLB02, FLB05, FLB07, FLB08 to 6 only.

Papadopoulos overtakes only the experiments FLB01-FLB10 of FatLim designation, and his selection became the traditional setup. Froustey in [34] provides inputs for additional FLB11 and FLB13 sets. FLB12 set in FatLim is based on the paper [40] but is reflected by any result neither in [34] nor in [35].

Froustey refers in [34] to the 3rd lot to have the same static material parameters as the lot No. 2. Only 8 specimens were used in the staircase evaluation per one kind of loading. No uniaxial tests with alternate loading were realized. While creating FatLim, Papuga initially took over the experiments published by Weber in his PhD thesis [12]. These experiments realized also on 30NCD16 are ascribed to Dubar [41]. Dubar in his original thesis [41] states that he took over Froustey’s experiments from [34-35]. He notes eight different lots of the material and scales the load levels on the basis of static material properties in order to get one set with uniform material properties. Because Froustey did realized neither static nor uniaxial fatigue experiments for the 3rd lot, it is unclear, where the applied correction factors originated.

Finding the final verdict in this case is hard. If we stay with checking applicability of the FLB set only, it can be applied as it is, because both uniaxial and multiaxial experiments were completed. FLB12 should be removed from the set at all. Weights of most of items can be set to 1.0, only the weights of those four fatigue limits explicitly noted above are decreased to 0.5. Weight of FLB04-FLB10 items equals 1 for criteria that do not use f_0 and 0.5 for those using it.

3.4. Lempp

Lempp’s experiments from his PhD thesis [5] are added by Papadopoulos in 1997 [16] to the original set from 1994 [15]. The experiments concern push-pull loading combined with torsion of 42CrMo4V. Unfortunately, the raw data of experiments are not provided, only figures of data points in the S-N curves and the regression lines, which are sketched there without any exact formulation. It seems that the values of fatigue limits provided in papers referring to Lempp are a mere wish of the first person who decided to take over the data. In order to process the data, the graphs were scanned and electronically processed by the WebPlotDigitizer application [42].

The only optimum section through the set of S-N curve if extrapolation is forbidden can be defined at 200.000 cycles. Lem03, Lem07, Lem 10 can be immediately removed because its low number of data points. The fatigue limit in repeated axial loading f_0 cannot be set at all, because the three points lie below 100.000 cycles. Removing it, all experiments with non-zero (Lem05-Lem10) are applicable for testing only if the evaluated criterion is not based on its value.

Lempp also evaluated the effect of the material anisotropy. It affects at least the criteria based on the critical plane. The decrease of the fatigue strength to approx. 83% is exhibited at 200.000 cycles, if the transverse orientation is evaluated to the longitudinal orientation of the specimen. Most of the present day criteria do not count with the correction for anisotropy, so this issue could be sensed as the major reason for removing this set completely.

Table 4. Overview of experimental data provided by Lempp [5]. Because Kohout and Věchet formula is based on four material parameters, only the curves described by more than 4 data points were evaluated by it. Additional weight factor 0.5 was applied by all data items due to the fact that they relate to data read from scans.

42CrMo4	data points	R^2		weight
		Basquin [3]	K&V [4]	
Lem01	6+4	0.531	0.707	0.5·0.6=0.3
Lem02	7+2	0.892	0.987	0.5·0.8=0.4
Lem03	3+1	-7.545	x	0
Lem04	5+1	0.830	0.948	0.5·0.4=0.25
Lem05	4+4	0.934	x	0.5·0.2=0.1 only if f_0 unnecessary
Lem06	6+3	0.565	0.730	0.5·0.6=0.3 only if f_0 unnecessary
Lem07	3+3	-3.321	x	0
Lem08	6+1	0.262	0.764	0.5·0.6=0.3 only if f_0 unnecessary
Lem09	4+2	0.581	x	0 (too large scatter)
Lem10	3+0	0.914	x	0
Lem f_{-1}	7+2	0.964	0.969	
Lem t_{-1}	7+2	0.624	0.730	
Lem f_0	3+1	-4.288	x	

4. Study case Papadopoulos [16]

The test sets described in the previous section are the heart of the most data sets (Table 2). In some cases [16, 22, 26], they present the only input for testing. If the evaluation of the individual items is summarized in Table 5, the total output results in 23.25. I.e. accepting the weighting process described in the previous section means that the set of original 44 data items is reduced approximately to its half i.e. 23.25 experiments.

The proposed weighting scheme is obviously subjective, and other weight system can be proposed. If the full weight is set to all left data items, then the total number of effective fatigue limit is 33. But such set would give the same importance to fatigue limits derived from S-N curves based on 8 and 4 data points, which is apparently incorrect. A more realistic outcome thus is the expectation that some equivalent number of fatigue limits is between 20 and 28 even if some other weighting system is adopted.

Because not only the size of the set is reworked, but also the content of NKh and Lem sets is touched, the complete evaluation of methods tested by Papadopoulos in [16] is realized in the next part. It concerns four multiaxial fatigue limit estimates: by Crossland, Matake, McDiarmid and Papadopoulos. Sines method was removed from the evaluation because it necessitates use of the fatigue limit in repeated axial loading f_0, which is not available in many cases. Dietmann's solution was not analyzed, because it has not been programmed in the software tool used for analyses yet.

Table 5. Description of the weights of the individual data items left in the Papadopoulos test set after the scrutiny. The total weight of the test set reaches 23.25 out of the original 44 data points.

Total	Nkh01	NKh09	NKh10
0.6	0.2	0.2	0.2

Total	Lem01	Lem02	Lem04	Lem05	Lem06	Lem08
1.65	0.3	0.4	0.25	0.1	0.3	0.3

Total	FLB01	FLB02	FLB03	FLB04	FLB05	FLB06	FLB07	FLB08	FLB09	FLB10
8	1	0.5	1	1	0.5	1	0.5	0.5	1	1

Total	HRZ01	HRZ02	HRZ03	HRZ04	HRZ05	HRZ06	HRZ07	HRZ08	HRZ09	HRZ10	HRZ11	HRZ12	HRZ13	HRZ14
13	1	1	1	0.5	1	0.5	1	1	1	1	1	1	1	1

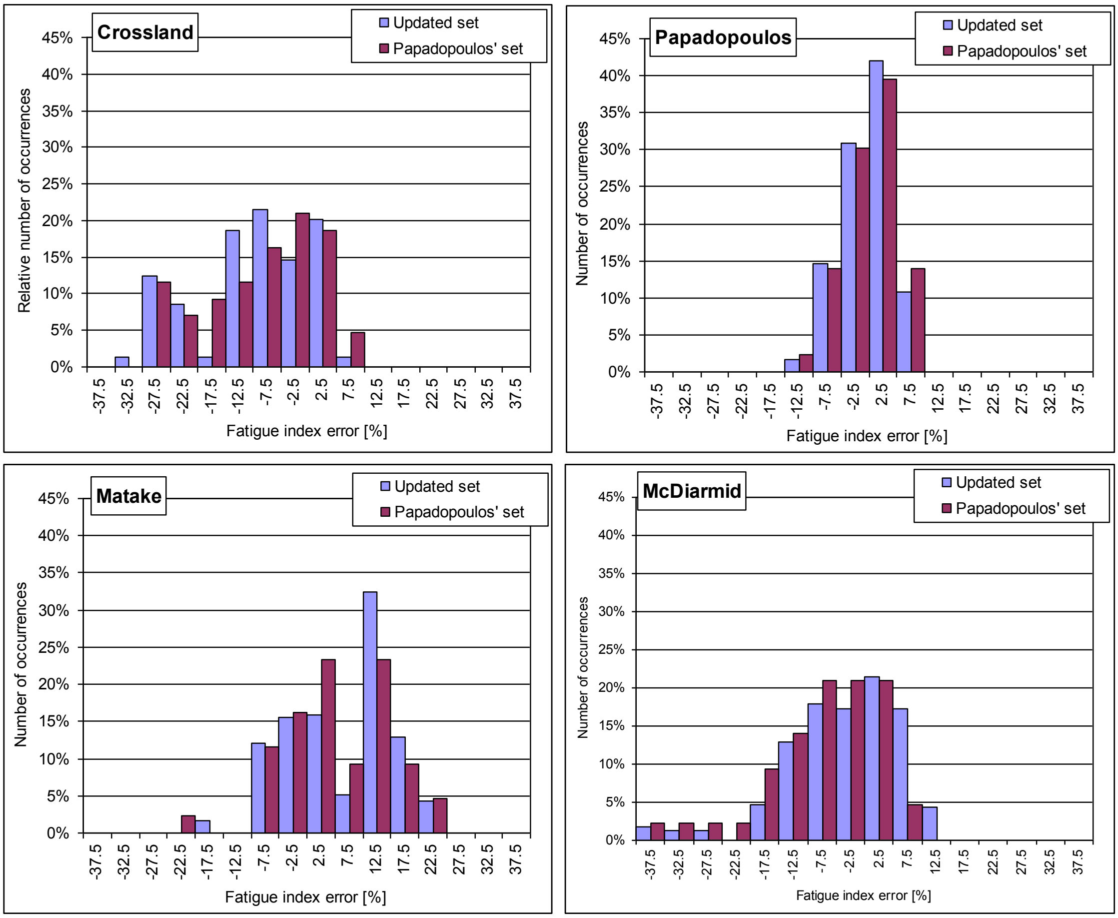

Fig. 2. Comparison of relative occurrence of fatigue index errors in the original Papadopoulos' set [16] and the new one defined here by Table 5.

Though the trends in Fig. 2 are close to coincidence, it is necessary to remind that the overall set is equal to approximately 23 fatigue limit items, which is a very low number. In such a case, several new experiments with full weights can substantially affect the overall distribution. Thanks to the experience gained during preparing [13], it is expected that other data sets will influence the shape of histograms much more. FADOFF consortium overtook the activity of the author in preparing the fatigue data databases and prepares a separate end point to it on the consortium webpage www.fadoff.eu.

5. Next steps

In order to simplify the future access to such kind of data items, they are saved to structured csv files within a specialized application FinLiv prepared as an MS Excel sheet equipped with an additional macro code. The csv files serve as the primary input during the whole computation line depicted in the sketch of Fig. 3. Thanks to saving also geometric characteristics of the specimens used for experimental analysis, APDL macro built for ANSYS finite element solver is capable to prepare the mesh and run the solution for most common geometries of fatigue notched specimens and various common load modes. The FinLiv application is used for storing the fatigue data, but also allows the user to run the regression analysis and to prepare an input file for selected fatigue solvers. Most of the fatigue solvers can automatically read ANSYS FE-results and the text input file for automated setup of the fatigue analysis can be prepared, the manual inputs are minimized in order to save time and labour and to speed up the evaluation process.

The focus of the FinLiv application is more general than on evaluating the fatigue limit criteria. Anyhow, another specialized fatigue software is prepared within FADOFF consortium. The so-called “Dummy Model” is an APDL macro intended to simulate the FE-solution on an artificially created mesh and stress history records in individual nodes of the mesh. The technology was already announced in 2012 [44], but the process of evaluating the input data for such a simulation took substantially longer than originally expected. The major significance of this solution is based on the fact that also the most often fatigue solvers will be able to read this Ansys result file. Its application in fatigue solvers thus can serve as the optimum way of validation.

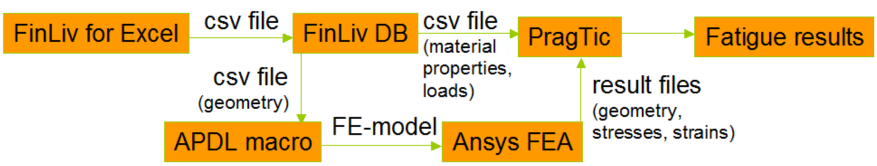

Fig. 3. Sketch of the data flow in the data processing line during the upcoming validation studies.

6. Conclusion

The paper provides an overview on the traditions ruling among researchers while selecting the optimum test set for testing newly proposed multiaxial methods for the fatigue limit estimation. It manifests, that the crucial paper by Papadopoulos et al. [16] affected the researchers significantly, and the data sets they used there are further transmitted to the next papers. The paper exhibits, though obviously not by a complete coverage, that the most often reused data set can be traced back to Nishihara & Kawamoto [1]. The paper evaluates their original work and explains that from its 32 items cited in various papers, only 3 for hard steel can be accepted as valid. This admittance is very reluctant and therefore the weight of these experiments is diminished by factor five, if compared with a fatigue limit input from an optimum set.

A similar evaluation is devoted to other partial sets forming the Papadopoulos' test set. It is documented that Lempp PhD thesis [5] cannot be accepted with full weight as well. The other two sets by Froustey [35] and Heidenreich et al. [33] are the only reliable items. The weights proposed for the individual items of the total test set are provided in Table 5. The weight of the whole set is diminished from 44 to 23.25 effective fatigue limit items.

The reduced set is evaluated by four methods analyzed by Papadopoulos in [16]. Surprisingly, the overall probability distribution documented in Fig. 2 does not change substantially, which means that the balance among various competing effects has not changed very much even after the reduction of the test set presented here. Anyhow, the low number of items of the final test set allows the user to realize only a rough statistics of the overall results, with minimum understanding of the concurring effects of e.g. the mean stress value, phase shift, load channels combinations etc.

A similar study is envisaged being realized for all data items, which FADOFF consortium is ready to analyze. The most important parts of the technologies making that possible are described in Sec. 5.

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